Feed form and energy concentration of the diet affect growth performance and digestive tract traits of brown-egg laying pullets from hatching to 17 weeks of age[1]

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ABSTRACT The influence of feed form and energy concentration of the diet on growth performance and the development of the gastrointestinal tract (GIT) was studied in brown-egg laying pullets. Diets formed a 2 x 5 factorial with 2 feed forms (mash vs. crumbles) and 5 levels of energy differing in 50 kcal AME_n/kg. For the entire study (0 to 17 wk of age) feeding crumbles increased ADFI (52.9 vs. 49.7 g; $P < 0.001$) and ADG (12.7 vs. 11.6 g; $P < 0.001$) and improved feed conversion ratio (FCR; 4.18 vs. 4.27; $P < 0.001$). An increase in the energy content of the diet decreased ADFI linearly ($P < 0.001$) and improved FCR quadratically ($P < 0.01$) but energy intake (kcal AME_n/d) was not affected. BW uniformity was higher ($P < 0.05$) in pullets fed crumbles than in those fed mash but was not affected ($P > 0.05$) by energy content of the diet. At 5, 10, and 17 wk of age, the relative weight (RW, % BW) of the GIT and the gizzard, and gizzard digesta content were lower ($P < 0.05$ to $P < 0.001$) and gizzard pH was higher ($P < 0.05$ to $P < 0.001$) in pullets fed crumbles than in pullets fed mash. Energy concentration of the diet did not affect any of the GIT variables studied. In summary, feeding crumbles improved pullet performance and reduced the RW of the GIT and gizzard, and increased gizzard pH at all ages. An increase in the energy content of the diet improved FCR from 0 to 17 wk of age. The use of crumbles and the increase in the AME_n content of the diet might be used adventageously when the objetive is to increase the BW of the pullets. However, crumbles affected the development and weight of the organs of the GIT, which might have negative effects on feed intake and egg production at the beginning of the egg laying cycle.

Key words: BW uniformity, crumble diet, gizzard pH, mash diet

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INTRODUCTION

Pelleting results usually in increases in feed intake (**FI**) and improvements of ADG and feed conversion ratio (**FCR**) in poultry (Abdollahi et al., 2013; Guzmán et al., 2015; Jiménez-Moreno et al., 2015). When the diets are fed as pellets, feed wastage is reduced (Serrano et al., 2013) and nutrient utilization is increased (Lemme et al., 2006; Abdollahi et al., 2011). Pelleting reduces the relative weight (**RW**; % BW) of the gizzard and increases gizzard pH in poultry (Preston et al., 2000; Abdollahi et al., 2011), effects that might be less pronounced in pullets because of their reduced growth rate and lower ingesta capacity (Frikha et al., 2009b; Guzmán et al., 2015). However, the information available on the influence of feed form on growth performance and the development of the gastrointestinal tract (**GIT**) in pullets is limited.

Energy concentration of the diet affects ADFI and growth performance of broilers (Brickett et al., 2007), pullets (Frikha et al., 2009a; Guzmán et al., 2015), and laying hens (Grobas et al., 1999a; Pérez-Bonilla et al., 2012). Birds eat to satisfy their energy requirements and therefore, voluntary FI decreases as the energy content of the diet increases (Leeson et al., 1996; Veldkamp et al., 2005). However, the adaptation of the digestive tract of the birds to regulate FI with changes in energy concentration of the diet might not be complete. For example, high energy diets contain more fat and are more palatable than low energy diets which may result in an increase in energy intake (**EI**) and BW gain (Grobas et al., 1999b). Moreover, an increase in the fat content of the diet reduces digesta transit time and improves the utilization of other components of the diet (Mateos and Sell 1980, 1981). In contrast, if the diet is diluted excessively, birds might not be able of maintaining their EI constant, resulting in poor performance (Nielsen, 2004; Pérez-Bonilla et al., 2012). On the other hand, when the energy concentration of the diet is reduced, fiber content increases, which benefits the development and function of the GIT (González-Alvarado et al., 2007; Jiménez-Moreno et al., 2009a; Sacranie et al., 2012). In this respect, Frikha et al. (2009a) reported that from 1 to 45 d of age, pullets fed low-energy diets had higher RW of the gizzard and GIT than pullets fed high-energy diets.

We hypothesized that pullets fed crumbles and high-energy diets could show improved BW and feed efficiency but also poorer development of the GIT than pullets fed mash and low-energy diets. The objective of the study was to compare the effects of feed form and energy concentration of the diet and their potential interactions on growth performance and GIT development of brown-egg laying pullets from hatching to 17 wk of age.

MATERIALS AND METHODS

Husbandry, Diets, and Study Design

The study procedures were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007).

Upon arrival to the study facility, pullets (1-day-old Lohmann Brown Classic) were weighed individually (36.7 ± 2.84 g) and allotted in groups of 50 birds into 60 cages (Facco S.A., Padova, Italy) provided with an open-trough feeder and 2 nipple drinkers. The average BW of the pullets was similar for all cages. Chicks were beak-trimmed at the hatchery and vaccinated against main diseases (Infectious Bronchitis Disease, Infectious Bursal Disease, Newcastle Disease, and *Salmonella* spp.) according to accepted commercial practices in Spain (Lohmann, 2013). Because of the dimensions ($80 \times 68 \times 40$ cm) of the cages, only 22 pullets chosen at random formed the study unit after 3 wk of age. The environmental conditions of the room were controlled automatically according to the age of the birds. The light program consisted on 22 h/d for the first wk of life and then, light was decreased 2 h/wk until reaching 12 h at 7 wk of age. From 7 to 17 wk of age, the light program was kept constant. Room temperature was maintained at 32 ± 1.5°C for the first 3 d of life and then, it was reduced gradually until reaching 21°C at 5 wk of age. Pullets had free access to feed and water throughout the trial.

The feeding program consisted in 3 types of diet that were supplied from 0 to 5, 5 to 10, and 10 to 17 wk of age. Within each feeding period, 5 diets [very low energy (**VLE**), low energy (**LE**), medium energy (**ME**), high energy (**HE**), and very high energy (**VHE**)] that differed in 50 kcal AME_n/kg but with similar indispensable amino acids and nutrient content per unit energy, were manufactured. The AME_n of the diets varied from 2,850 to 3,050 kcal/kg from 0 to 5 wk, 2,700 to 2,900 kcal/kg from 5 to 10 wk, and 2,600 to 2,800 kcal/kg from 10 to 17 wk. For the manufacturing of the diets all the ingredients were ground with a hammer mill (Model MRA 220, Rosal S.A., 08130, Barcelona, Spain) fitted with a 2-mm (diets fed from 0 to 5 wk) or a 3-mm (diets fed from 5 to 17 wk of age) screen. All diets contained a commercial enzyme complex with xylanase and β-glucanase activities (Roxazyme, DSM S.A., Madrid, Spain). In the formulation of the diets it was assumed that the inclusion of the enzyme complex increased by 2% the AME_n content of the wheat (from 3,150 to 3,213 kcal/kg) and barley (from 2,800 to 2,856 kcal/kg) but had no effects on the energy content of the other ingredients (Fundación Española Desarrollo Nutrición Animal, 2010). Within each feeding period, the 2 summit diets (VLE and VHE) were formulated according to the recommendations of Fundación Española Desarrollo Nutrición Animal (2008) and the intermediate feeds resulted from the mixing in adequate portions of the 2 summit diets. Then, all feed batches (3 feeding periods and 5 diets/period) were divided into 2 portions; the first portion was used as such and the second portion was steam-conditioned at 72°C for 60 s, passed through a pellet press (Model PVR 180 2T, Mabrik, Barcelona, Spain) provided with a 60-mm thick die and a 3-mm screen, and crumbled. The ingredient composition and the calculated nutrient content (Fundación Española Desarrollo Nutrición Animal, 2010) of the study diets used in the 3 feeding periods are shown in Tables 1–3, respectively. Diets from 0 to 5 wk of age had similar ingredient composition than the diets used in the research of Guzmán et al. (2015) but the batches were manufactured at different times.

The study design was completely randomized with 10 treatments in a factorial arrangement with 2 feed forms (crumbles vs. mash) and 5 energy levels (VLE, LE, ME, HE, and VHE). Each treatment was replicated 6 times and the study unit was the cage for all measurements.

Laboratory Analysis

Representative samples of the diets were ground in a laboratory mill (Retsch Model Z-I, Stuttgart, Germany) equipped with a 1-mm screen and analyzed for moisture by oven-drying (Method 930.15), total ash using a muffle furnace (Method 942.05), crude fiber by sequential extraction with diluted acid and alkali (Method 962.09), and nitrogen by Dumas (Method 968.06) using a Leco analyzer (Model FP-528, Leco Corp., St. Joseph, MI) as indicated by AOAC International (2005). Also, the dietary fiber content of the sunflower meal and soybean meal was determined (Megazyme International, Bray, Ireland) according to Method 991.43 of the AOAC International (2005). Gross energy of the diets was determined with an adiabatic bomb calorimeter (Model 1356, Parr Instrument Company, Moline, IL). The amino acid content of the 2 extreme diets (VLE and VHE) of each of the 3 feeding periods was determined by ion-exchange

Table 1. Ingredient composition and calculated and determined analyses (percent as-fed basis, unless otherwise indicated) of the study diets[1] (0 to 5 wk of age).

	VLE	LE	ME	HE	VHE
Ingredient					
Corn	35.0	35.0	35.0	35.0	35.0
Wheat	19.2	18.3	17.4	16.6	15.7
Soybean meal, 45.5% CP	33.3	35.0	36.7	38.4	40.1
Sunflower meal, 28% CP	6.0	4.5	3.0	1.5	-
Soy oil	2.71	3.39	4.08	4.69	5.37
Dicalcium phosphate	2.07	2.07	2.07	2.06	2.06
Calcium carbonate	1.04	1.05	1.05	1.05	1.06
Sodium chloride	0.35	0.35	0.35	0.35	0.35
DL-methionine, 99%	0.13	0.14	0.15	0.15	0.16
Vitamin-trace mineral premix[2]	0.20	0.20	0.20	0.20	0.20
Calculated analyses[3]					
AME_n (kcal/kg)	2,850	2,900	2,950	3,000	3,050
Ether extract	5.1	5.7	6.4	7.0	7.7
Crude fiber	4.5	4.2	3.9	3.6	3.3
Neutral detergent fiber	11.1	10.5	10.0	9.4	8.9
Dietary fiber	17.6	17.2	16.8	16.4	16.0
CP	21.7	22.0	22.2	22.5	22.7
Digestible amino acid					
Arg	1.32	1.34	1.35	1.37	1.38
Ile	0.80	0.82	0.83	0.84	0.85
Lys	0.97	0.99	1.02	1.05	1.08
Met	0.43	0.44	0.44	0.45	0.46
Met + Cys	0.72	0.73	0.74	0.75	0.76
Thr	0.68	0.70	0.71	0.72	0.73
Trp	0.23	0.23	0.23	0.24	0.24
Val	0.89	0.90	0.91	0.92	0.93
Calcium	1.10	1.10	1.10	1.10	1.10
Total phosphorus	0.82	0.82	0.81	0.80	0.80
Digestible phosphorus	0.44	0.43	0.43	0.43	0.43
Determined analyses[4]					
DM	91.1	91.0	90.7	90.0	90.9
Gross energy (kcal/kg)	4,160	4,175	4,181	4,230	4,286
Ether extract (HCl hydrolisis)	5.6	6.1	6.4	7.2	7.5
Crude fiber	4.1	3.8	3.8	3.6	3.2
CP	21.3	21.8	22.5	22.6	23.5
Total amino acid[5]					
Arg	1.44	-	-	-	1.54
Ile	0.91	-	-	-	1.00
Lys	1.13	-	-	-	1.21
Met	0.46	-	-	-	0.52
Met + Cys	0.84	-	-	-	0.90
Thr	0.83	-	-	-	0.87
Val	1.00	-	-	-	1.07
Total ash	5.9	6.7	6.6	6.4	5.9

[1]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[2]Supplied per kilogram diet: vitamin A (trans-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 3,500 IU; vitamin E (all-*rac*-tocopherol-acetate), 35 mg; vitamin B_1, 2 mg; vitamin B_2, 8 mg; vitamin B_6, 4 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; vitamin K_3 (bisulphate menadione complex), 3 mg; choline (choline chloride), 270 mg; nicotinic acid, 60 mg; pantothenic acid (D-calcium pantothenate), 15 mg; folic acid, 1.5 mg; D-biotin, 0.15 mg; zinc (ZnO), 90 mg; manganese (MnO), 75 mg iron ($FeCO_3$), 60 mg; copper ($CuSO_4{\cdot}5H_2O$), 8 mg; iodine (KI), 2 mg; selenium (Na_2SeO_3), 0.3 mg; Roxazyme, 200 mg [1,600 U endo-1,4-β-glucanase (EC 3.2.1.4), 3,600 U endo-1,3 (4)-β-glucanase (EC 3.2.1.6), and 5,200 U endo-1,4-β-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain; and Natuphos 5000 [300 FTU/kg 6-phytase (EC 3.1.3.26), 60 mg, supplied by Basf Española S.A, Tarragona, Spain].

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

[4]Data correspond to the average of the mash and crumble diets. The differences in values between the mash and crumble diets were within acceptable ranges.

[5]The amino acids were determined only in the two summit diets.

chromatography (Hewlett-Packard 1100, Waldbronn, Germany) after acid hydrolysis, as indicated by De Coca-Sinova et al. (2008). Tryptophan was not determined. The chemical analyses of the study diets of the 3 feeding periods (average of the 2 feed forms) are shown in Tables 1–3. Particle size distribution and mean particle size of the mash and crumble diets, expressed as geometric mean diameter (**GMD**), were determined by dried sieving as outlined by ASAE (1995) in 100-g samples using a shaker (Retsch, Stuttgart, Germany) provided with 8 sieves ranging in mesh from 5,000 to 40 μm (Table 4). All the analyses were conducted in duplicate, except for the GMD of the diets that were determined in triplicate.

Table 2. Ingredient composition and calculated and determined analyses (percent as-fed basis, unless otherwise indicated) of the study diets[1] (5 to 10 wk of age).

	VLE	LE	ME	HE	VHE
Ingredient					
Corn	35. 0	35.0	35.0	35.0	35.0
Wheat	-	2.5	5.0	7.5	10.0
Barley	28.0	25.6	23.3	20.9	18.5
Soybean meal, 45.5% CP	22. 0	24.3	26.5	28.8	31.0
Sunflower meal, 32% CP	10.0	7.5	5.0	2.5	-
Soy oil	1.0	1.25	1.50	1.75	2.0
Dicalcium phosphate	1.53	1.55	1.57	1.58	1.60
Calcium carbonate	1.64	1.52	1.40	1.28	1.16
Sodium chloride	0.35	0.35	0.34	0.34	0.33
DL-methionine, 99%	0.11	0.12	0.13	0.14	0.15
L-threonine, 98%	0.08	0.08	0.07	0.07	0.06
L-lysine·HCl, 78%	0.09	0.07	0.05	0.02	-
Vitamin-trace mineral premix[2]	0.20	0.20	0.20	0.20	0.20
Calculated analyses[3]					
AME_n (kcal/kg)	2,700	2,750	2,800	2,850	2,900
Ether extract	3.4	3.7	3.9	4.2	4.4
Crude fiber	5.4	4.9	4.4	3.9	3.5
Neutral detergent fiber	13.6	12.8	12.0	11.2	10.4
Dietary fiber	19.4	18.8	18.2	17.5	16.9
CP	19.0	19.2	19.4	19.7	19.9
Digestible amino acid					
Arg	1.13	1.14	1.15	1.16	1.17
Ile	0.68	0.69	0.70	0.71	0.73
Lys	0.84	0.86	0.87	0.88	0.90
Met	0.39	0.39	0.40	0.41	0.41
Met + Cys	0.65	0.66	0.67	0.68	0.69
Thr	0.67	0.67	0.68	0.68	0.68
Trp	0.19	0.20	0.20	0.20	0.21
Val	0.78	0.79	0.80	0.81	0.82
Calcium	1.03	0.98	0.94	0.89	0.85
Total phosphorus	0.76	0.76	0.75	0.74	0.73
Digestible phosphorus	0.43	0.44	0.44	0.44	0.44
Determined analyses[4]					
DM	90.4	90.6	91.1	91.5	91.9
Gross energy (kcal/kg)	3,962	3,993	3,997	3,993	4,054
Ether extract (HCl hydrolisis)	3.5	3.8	4.2	3.9	4.6
Crude fiber	6.2	6.5	5.9	5.9	5.4
CP	18.3	18.1	18.2	19.0	18.6
Total amino acid[5]					
Arg	1.25	-	-	-	1.30
Ile	0.77	-	-	-	0.84
Lys	0.99	-	-	-	1.05
Met	0.42	-	-	-	0.46
Met + Cys	0.73	-	-	-	0.79
Thr	0.77	-	-	-	0.81
Val	0.92	-	-	-	0.95
Total ash	5.0	5.5	5.8	6.9	6.2

[1]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; VHE, and very high energy).

[2]Supplied per kilogram diet: vitamin A (trans-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 3,000 IU; vitamin E (all-*rac*-tocopherol-acetate), 30 mg; vitamin B_1, 2 mg; vitamin B_2, 8 mg; vitamin B_6, 4 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; vitamin K_3 (bisulphate menadione complex), 3 mg; choline (choline chloride), 250 mg; nicotinic acid, 60 mg; pantothenic acid (D-calcium pantothenate), 15 mg; folic acid, 1.5 mg; D-biotin, 0.15 mg; zinc (ZnO), 80 mg; manganese (MnO), 75 mg iron ($FeCO_3$), 60 mg; copper ($CuSO_4 \cdot 5H_2O$), 8 mg; iodine (KI), 2 mg; selenium (Na_2SeO_3), 0.25 mg; Roxazyme, 200 mg [1,600 U endo-1,4-β-glucanase (EC 3.2.1.4), 3,600 U endo-1,3 (4)-β-glucanase (EC 3.2.1.6), and 5,200 U endo-1,4-β-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain; and Natuphos 5000 [300 FTU/kg 6-phytase (EC 3.1.3.26), 60 mg, supplied by Basf Española S.A, Tarragona, Spain].

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

[4]Data correspond to the average of the mash and crumble diets. The differences in values between the mash and crumble diets were within acceptable ranges.

[5]The amino acids were determined only in the two summit diets.

Measurements

Individual BW of the pullets and feed disappearance were recorded by replicate at 5, 10, and 17 wk of age. Any mortality was recorded and weighed as produced. From these data, ADFI, ADG, FCR, EI (kcal AME_n/d), energy conversion ratio (kcal AME_n/g BW gain), and BW uniformity were determined by period and cumulatively. BW uniformity was determined by replicate as indicated by Peak et al. (2000). Briefly, the

Table 3. Ingredient composition and calculated and determined analyses (percent as-fed basis, unless otherwise indicated) of the study diets[1] (10 to 17 wk of age).

	VLE	LE	ME	HE	VHE
Ingredient					
Wheat	31.5	33.6	35.7	37.8	40.0
Corn	20.0	20.0	20.0	20.0	20.0
Barley	10.0	10.1	10.3	10.4	10.5
Soybean meal, 45.5% CP	9.0	11.0	13.0	15.0	17.0
Sunflower meal, 28% CP	15.0	13.3	11.5	9.8	8.0
Bran	10.0	7.5	5.0	2.5	-
Soy oil	0.85	0.94	1.03	1.11	1.20
Dicalcium phosphate	1.50	1.51	1.51	1.52	1.53
Calcium carbonate	1.44	1.37	1.29	1.23	1.16
Sodium chloride	0.35	0.35	0.35	0.35	0.35
DL-methionine, 99%	0.05	0.05	0.06	0.06	0.06
L-lysine·HCl, 78%	0.11	0.08	0.06	0.03	-
Vitamin-trace mineral premix[2]	0.20	0.20	0.20	0.20	0.20
Calculated analyses[3]					
AME_n (kcal/kg)	2,600	2,650	2,700	2,750	2,800
Ether extract	3.1	3.1	3.2	3.3	3.3
Crude fiber	7.1	6.6	6.0	5.5	5.0
Neutral detergent fiber	18.0	16.7	15.5	14.2	13.0
Dietary fiber	22.1	21.1	20.0	19.0	17.9
CP	16.1	16.4	16.7	16.9	17.2
Digestible amino acid					
Arg	0.92	0.94	0.95	0.97	0.98
Ile	0.53	0.55	0.57	0.58	0.60
Lys	0.61	0.62	0.63	0.64	0.65
Met	0.29	0.30	0.30	0.31	0.31
Met + Cys	0.53	0.54	0.55	0.55	0.56
Thr	0.45	0.46	0.48	0.49	0.50
Trp	0.16	0.17	0.17	0.18	0.18
Val	0.63	0.64	0.65	0.67	0.68
Calcium	1.07	1.05	1.02	1.00	0.97
Total phosphorus	0.77	0.75	0.73	0.71	0.69
Digestible phosphorus	0.37	0.36	0.36	0.35	0.35
Determined analyses[4]					
DM	91.4	91.3	91.7	91.4	91.3
Gross energy (kcal/kg)	4,016	4,023	3,958	4,054	4,001
Ether extract (HCl hydrolisis)	3.0	3.2	3.0	3.3	3.1
Crude fiber	6.6	6.2	5.8	5.9	5.2
CP	16.1	15.9	16.4	17.5	16.4
Total amino acid[5]					
Arg	1.03	-	-	-	1.09
Ile	0.62	-	-	-	0.69
Lys	0.69	-	-	-	0.76
Met	0.31	-	-	-	0.34
Met + Cys	0.64	-	-	-	0.65
Thr	0.52	-	-	-	0.60
Val	0.74	-	-	-	0.80
Total ash	5.7	6.0	6.0	4.6	5.3

[1]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; VHE, and very high energy).

[2]Supplied per kilogram diet: vitamin A (trans-retinyl acetate), 9,000 IU; vitamin D_3 (cholecalciferol), 3,000 IU; vitamin E (all-*rac*-tocopherol-acetate), 25 mg; vitamin B_1, 2 mg; vitamin B_2, 8 mg; vitamin B_6, 4 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; vitamin K_3 (bisulphate menadione complex), 3 mg; choline (choline chloride), 200 mg; nicotinic acid, 60 mg; pantothenic acid (D-calcium pantothenate), 15 mg; folic acid, 1.5 mg; D-biotin, 0.15 mg; zinc (ZnO), 75 mg; manganese (MnO), 70 mg iron ($FeCO_3$), 45 mg; copper ($CuSO_4{\cdot}5H_2O$), 7 mg; iodine (KI), 2 mg; selenium (Na_2SeO_3), 0.2 mg; Roxazyme, 200 mg [1,600 U endo-1,4-β-glucanase (EC 3.2.1.4), 3,600 U endo-1,3 (4)-β-glucanase (EC 3.2.1.6), and 5,200 U endo-1,4-β-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain; and Natuphos 5000 [300 FTU/kg 6-phytase (EC 3.1.3.26), 60 mg, supplied by Basf Española S.A, Tarragona, Spain].

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

[4]Data correspond to the average of the mash and crumble diets. The differences in values between the mash and crumble diets were within acceptable ranges.

[5]The amino acids were determined only in the two summit diets.

CV of the individual BW of the pullets of each cage was generated and this variable was used as an indirect measurement of BW uniformity. For the determination of GIT traits, birds were fasted for 60 min after the corresponding growth performance control and then fed ad libitum for 3 h to maximize FI and digesta content. Then, 2 birds/replicate were randomly selected, weighed, and euthanized by CO_2 inhalation. The GIT (from the post-crop esophagus to the cloaca, including digesta content, liver, pancreas, and spleen)

Table 4. Particle size distribution[1] and geometric mean diameter (GMD, μm) of the experimental diets.[2]

	VLE		LE		ME		HE		VHE	
	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble
From 0 to 5 wk of age										
Sieve diameter[3] (μm)										
2,500	12.0	9.3	9.7	10.0	11.3	6.9	10.9	4.6	10.3	4.8
1,250	27.3	65.4	30.0	57.8	28.7	54.8	27.9	50.6	26.0	50.1
630	31.7	19.3	32.7	20.9	33.2	24.3	33.6	28.7	35.4	28.6
315	18.4	4.0	17.7	8.2	17.4	9.9	18.0	11.2	17.7	11.3
160	10.2	2.2	9.6	2.8	8.6	3.8	8.9	4.5	10.8	4.8
GMD ± GSD[4]	950 ± 2.2	1,519 ± 1.7	951 ± 2.1	1,382 ± 1.9	957 ± 2.1	1,250 ± 1.8	938 ± 2.1	1,158 ± 1.9	952 ± 2.2	1,157 ± 1.9
From 5 to 10 wk of age										
Sieve diameter (μm)										
2,500	7.1	21.1	4.6	14.8	10.7	13.8	11.3	13.9	15.2	11.6
1,250	47.4	61.6	50.6	57.2	49.9	57.7	50.5	62.3	35.1	58.3
630	27.9	13.6	28.7	19.6	24.2	19.5	23.4	17.4	27.3	20.4
315	12.0	2.6	11.2	5.9	9.8	6.0	9.4	4.3	12.4	6.5
160	5.7	1.0	4.5	2.2	5.2	2.6	5.1	1.9	9.4	3.0
GMD ± GSD	1,172 ± 2.0	1,760 ± 1.7	1,158 ± 1.9	1,496 ± 1.8	1,267 ± 2.0	1,475 ± 1.8	1,294 ± 2.0	1,563 ± 1.7	1,112 ± 2.36	1,424 ± 1.84
From 10 to 17 wk of age										
Sieve diameter (μm)										
2,500	7.7	35.4	4.6	28.9	8.5	31.1	11.2	28.4	14.8	17.2
1,250	44.4	52.1	50.6	52.4	48.2	54.8	50.5	58.2	37.2	63.4
630	27.8	10.2	28.7	11.7	25.5	10.2	23.4	9.5	24.8	14.1
315	13.1	1.6	11.2	4.4	11.6	2.3	9.9	2.4	12.7	3.6
160	6.7	0.6	4.5	2.3	6.0	1.5	4.9	1.2	9.9	1.4
GMD ± GSD	1,127 ± 2.1	2,027 ± 1.7	1,158 ± 1.9	1,772 ± 1.9	1,193 ± 2.0	1,913 ± 1.7	1,302 ± 2.0	1,885 ± 1.7	1,112 ± 2.3	1,660 ± 1.7

[1]Geometric mean diameter.

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; VHE, and very high energy).

[3]The percentage of particles smaller than 160 μm or bigger than 2,500 μm were negligible for all diets.

[4]GSD = Log normal SD.

was removed aseptically and weighed. After GIT removal, the pullets were weighed again and carcass yield (% BW, including the head, neck, and feet) was calculated. Then, the liver and the full proventriculus and gizzard were carefully excised and weighed. The pH of the gizzard contents was measured in duplicate in situ using a digital pH meter fitted with a fine-tip glass electrode (Model 507, Crison Instruments S.A., Barcelona, Spain) as indicated by Jiménez-Moreno et al. (2009a). The average value of the 2 measurements was used for further analysis. Afterwards, the proventriculus and gizzard were emptied from any digesta, cleaned, dried with desiccant paper, and weighed again. The fresh digesta content of the 2 organs was calculated as the difference between the full and empty organ weight and expressed relative (i.e., percent) to full organ weight. In addition, the length of the small intestine (duodenum, jejunum, and ileum) from the gizzard to ileocecal junction, and of the 2 ceca (from the ostium to the tip of the ceca) were measured on a glass surface using a flexible tape with a precision of 1 mm, and expressed relative to full BW (**RL**, cm/kg BW). Body length of the pullet, from the tip of the beak to the end of longest phalanx, was also measured in extended birds. Finally, the length and diameter (in the middle point of the bone) of the tarsus were measured using a digital caliper, and expressed as cm/kg BW.

Statistical Analysis

Data on growth performance, BW uniformity, GIT traits, and body measurements were analyzed as a completely randomized design with feed form and energy concentration of the diet as main effects using the GLM procedure of SAS (SAS Institute, 2004). In addition, treatment sum of squares for the level of energy was partitioned into linear (**L**) and quadratic (**Q**) effects. When significant differences among treatments were observed, means were separated using the Tukey test. All differences were considered significant at $P < 0.05$.

RESULTS

The physico-chemical characteristics of the study diets of the 3 feeding periods are shown in Tables 1–3, and their GMD is shown in Table 4. The GMD of the mash diets were not affected by the energy content of the feed but that of the crumble diets decreased as the energy content increased. The determined dietary fiber content of the sunflower meal and the soybean meal used were 46.8 and 26.2%, respectively.

Growth Performance and BW Uniformity

Mortality was 2.7% and was not related to treatment (data not shown). Most of the mortality (2.6%) occurred during the first week life.

Table 5. Influence of feed form and energy content (kcal AME_n/kg) of the diet on ADFI, ADG, and feed conversion ratio (FCR) of the pullets from hatchery to 17 wk of age.[1]

	0 to 5 wk			5 to 10 wk			10 to 17 wk			0 to 17 wk		
Treatment	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR	ADFI (g)	ADG (g)	FCR
Feed form												
Mash	21.1^{a}	9.1^{b}	2.31^{a}	51.1^{b}	14.6^{b}	3.50^{a}	69.2^{b}	11.3^{b}	6.11	49.7^{b}	11.6^{b}	4.27^{a}
Crumbles	20.7^{b}	9.7^{a}	2.13^{b}	54.0^{a}	15.8^{a}	3.42^{b}	75.2^{a}	12.5^{a}	6.00	52.9^{a}	12.7^{a}	4.18^{b}
AME_n content[2]												
VLE	21.2^{a}	9.4	2.26^{a}	54.2^{a}	14.9	3.63^{a}	75.6^{a}	11.9	6.37^{a}	53.3^{a}	12.0	4.43^{a}
LE	21.0^{a,b}	9.4	2.24^{a,b}	53.5^{a}	15.1	3.54^{a}	73.3^{a,b}	11.9	6.18^{a,b}	52.1^{a,b}	12.1	4.31^{b}
ME	21.0^{a,b}	9.4	2.25^{a}	52.7^{a,b}	15.4	3.42^{b}	70.8^{b,c}	11.8	6.00^{b,c}	50.8^{b,c}	12.1	4.19^{c}
HE	20.8^{a,b}	9.5	2.19^{b,c}	51.7^{b,c}	15.3	3.37^{b}	71.1^{b,c}	12.0	5.92^{c}	50.6^{c}	12.2	4.13^{c,d}
VHE	20.6^{b}	9.5	2.17^{c}	50.8^{c}	15.2	3.34^{b}	70.0^{c}	12.1	5.82^{c}	49.8^{c}	12.2	4.08^{d}
SD[3]	0.53	0.26	0.045	1.36	0.62	0.089	2.47	0.64	0.246	1.25	0.31	0.062
							P-value					
Feed form	0.009	<.001	<.001	<.001	<.001	<.001	<.001	<.001	0.072	<.001	<.001	<.001
AME_n content												
L[4]	0.002	0.328	<.001	<.001	0.112	<.001	<.001	0.409	<.001	<.001	0.154	<.001
Q[5]	0.454	0.812	0.185	0.624	0.142	0.057	0.054	0.629	0.277	0.180	0.863	0.005

[1]Only main effects are shown. When a significant interaction was detected (ADFI and FCR from 0 to 5 wk and from 5 to 10 wk of age) the data are shown in Figure 1.

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[3]30 replicates for feed form and 12 replicates for AME_n content of the diet.

[4]L = Linear effect of energy content of the diet.

[5]Q = Quadratic effect of energy content of the diet.

[a–d]Within a column, means without a common superscript differ significantly.

Feed Form From 0 to 17 wk of age, pullets fed crumbles had greater ADFI (52.9 vs. 49.7 g; $P < 0.001$) and ADG (12.7 vs. 11.6 g; $P < 0.001$) and better FCR (4.18 vs. 4.27; $P < 0.001$) than pullets fed mash (Table 5). Consequently, EI was greater (146 vs. 137 kcal AME_n/d; $P < 0.001$) and energy conversion ratio was better (11.3 vs. 11.7 kcal AME_n/g; $P < 0.001$) with crumbles (Table 6). Similar results were observed in each of the 3 feeding periods, except from 0 to 5 wk, a period in which ADFI was lower ($P < 0.01$) in pullets fed crumbles than in pullets fed mash. Crumble feeding improved BW uniformity, consequently, with differences being significant at 10 ($P < 0.001$) and 17 ($P < 0.05$) wk of age (Table 7).

Energy Concentration of the Diet From hatching to 17 wk of age, ADFI decreased (L; $P < 0.001$) but ADG (L; $P = 0.054$) and FCR (Q; $P < 0.01$) improved as the energy content of the diet increased. No interactions between feed form and energy concentration of the diet were observed for ADG in any of the 3 feeding periods considered but some interactions were detected for ADFI and FCR. For example, from 0 to 10 wk of age, ADFI decreased and FCR improved as the energy content of the diet increased in pullets fed crumbles but no differences were detected in pullets fed mash ($P < 0.001$ and $P < 0.01$ for the interactions from 0 to 5 wk and $P < 0.01$ and $P < 0.001$ for the interactions from 5 to 10 wk of age for ADFI and FCR, respectively) (Figure 1). Consequently, EI increased as the AME_n of the diet increased in pullets fed mash but not in pullets fed crumbles ($P < 0.001$ and $P < 0.01$ for the interaction from 0 to 5 and 5 to 10 wk of age, respectively). BW uniformity was not affected by the energy content of the diet at any age.

GIT Traits and Body Measurements

Feed Form Feed form affected all GIT and body traits measured. At 5, 10, and 17 wk of age, carcass yield was higher ($P < 0.001$) in pullets fed crumbles than in pullets fed mash (Table 8). Liver weight was greater in pullets fed mash than in pullets fed crumbles at 5 wk of age ($P < 0.01$) but no effects were observed after this age. The fresh content of the proventriculus was greater ($P < 0.001$) in pullets fed crumbles than in pullets fed mash at all ages (Table 9). Also, the RW of the proventriculus was consistently greater ($P < 0.001$) in pullets fed crumbles than in pullets fed mash, but the differences were significant only at 17 wk of age. On the other hand, the full gizzard was lighter ($P < 0.001$) at all ages in pullets fed crumbles (Table 10) whereas gizzard digesta content was higher ($P < 0.05$ at 5 wk, $P = 0.06$ at 10 wk, and $P < 0.001$ at 17 wk of age) and gizzard pH was lower ($P < 0.05$ at 5 wk and $P < 0.001$ at 10 and 17 wk of age) in pullets fed mash. Pullets fed mash had longer small intestine at 5 wk of age ($P < 0.01$) and longer ceca at all ages ($P < 0.05$) than pullets fed crumbles (Table 11).

Body length ($P < 0.01$) and tarsus length ($P < 0.01$ at 5 wk and $P < 0.001$ at 10 and 17 wk of age) were

Table 6. Influence of feed form and energy content (kcal AME_n/kg) of the diet on energy intake (EI, kcal AME_n/d) and energy conversion ratio[2] (ECR, kcal AME_n/g) of the pullets from hatchery to 17 wk of age.[1]

	0 to 5 wk		5 to 10 wk		10 to 17 wk		0 to 17 wk	
Treatment	EI	ECR	EI	ECR	EI	ECR	EI	ECR
Feed form								
Mash	62.3^{a}	6.82^{a}	143^{b}	9.81^{a}	187^{b}	16.5^{a}	137^{b}	11.7^{a}
Crumbles	61.1^{b}	6.29^{b}	151^{a}	9.57^{b}	203^{a}	16.2^{b}	146^{a}	11.3^{b}
AME_n content[3]								
VLE	60.4^{b}	6.44^{a}	146	9.81	197	16.6	142	11.6
LE	61.0^{a,b}	6.48^{a,b}	147	9.74	194	16.4	141	11.5
ME	62.1^{a,b}	6.64^{a}	148	9.59	191	16.2	140	11.4
HE	62.3^{a,b}	6.59^{a,b}	147	9.62	196	16.3	142	11.5
VHE	62.7^{a}	6.63^{b}	147	9.69	196	16.3	142	11.5
SD[4]	1.55	0.131	3.79	0.250	6.62	0.662	3.41	0.282
				P-value				
Feed form	0.005	<.001	<.001	<.001	<.001	0.075	<.001	<.001
AME_n content								
L[5]	<.001	<.001	0.537	0.109	0.991	0.237	0.450	0.369
Q[6]	0.411	0.121	0.502	0.089	0.071	0.350	0.263	0.214

[1]Only main effects are shown. When a significant interaction was detected (EI and ECR from 0 to 5 wk and from 5 to 10 wk of age) the data are shown in Figure 1.

[2]ECR was obtained from the calculated AME_n intake and ADG of the pullets shown in Table 6.

[3]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[4]30 replicates for feed form and 12 replicates for AME_n content of the diet.

[5]L = Linear effect of energy content of the diet.

[6]Q = Quadratic effect of energy content of the diet.

[a–b]Within a column, means without a common superscript differ significantly.

Table 7. Influence of feed form and energy content (kcal AME_n/kg) of the diet on BW uniformity[1] of the pullets.

Treatment	5 wk	10 wk	17 wk
Feed form			
Mash	8.57	8.61^{a}	9.25^{a}
Crumbles	7.98	7.27^{b}	7.97^{b}
AME_n content[2]			
VLE	8.65	7.75	9.00
LE	8.02	7.71	8.12
ME	8.44	8.28	8.57
HE	7.71	7.97	8.43
VHE	8.58	7.99	8.95
SD[3]	1.473	1.282	2.111
		P-value[6]	
Feed form	0.123	<.001	0.022
AME_n content			
L[4]	0.744	0.502	0.921
Q[5]	0.236	0.570	0.330

[1]Evaluated as the CV (%) of the individual BW of the pullets from each pen (Peak et al., 2000).

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[3]Thirty replicates for feed form and 12 replicates for AME_n content of the diet.

[4]L = Linear effect of energy content of the diet.

[5]Q = Quadratic effect of energy content of the diet.

[6]The interactions between feed form and AME_n content of the diet were not significant ($P > 0.05$).

[a,b]Within a column, means without a common superscript differ significantly.

shorter at all ages in pullets fed crumbles than in pullets fed mash (Table 12). At 10 wk ($P < 0.01$) and 17 wk ($P < 0.05$) age, tarsus diameter was greater in pullets fed mash than in pullets fed crumbles.

Energy Concentration of the Diet Energy concentration of the diet did not affect any GIT or body trait at any age.

DISCUSSION

The GMD of the starter diets (0 to 5 wk) was lower than that of the 5 to 10 and 10 to 17 wk of age diets, consistent with the reduced size of the screen used for grinding the pre-starter diets. An increase in energy content did not affect the GMD of the mash diets but decreased that of the crumble diets. The ingredient composition of the diets varied as the energy concentration of the diet increased. In this respect, the high-energy diets contained more soy oil than the low-energy diets, and an increase in fat content may result in a loss of pellet quality, with higher proportion of fines and reduced GMD (Briggs et al., 1999). The dietary fiber content of the sunflower meal and soybean meal batches used was similar to values reported by Bach Knudsen (1997).

Growth Performance and BW Uniformity

Feed Form From hatching to 17 wk of age, pullets fed crumbles had greater ADFI and ADG and better

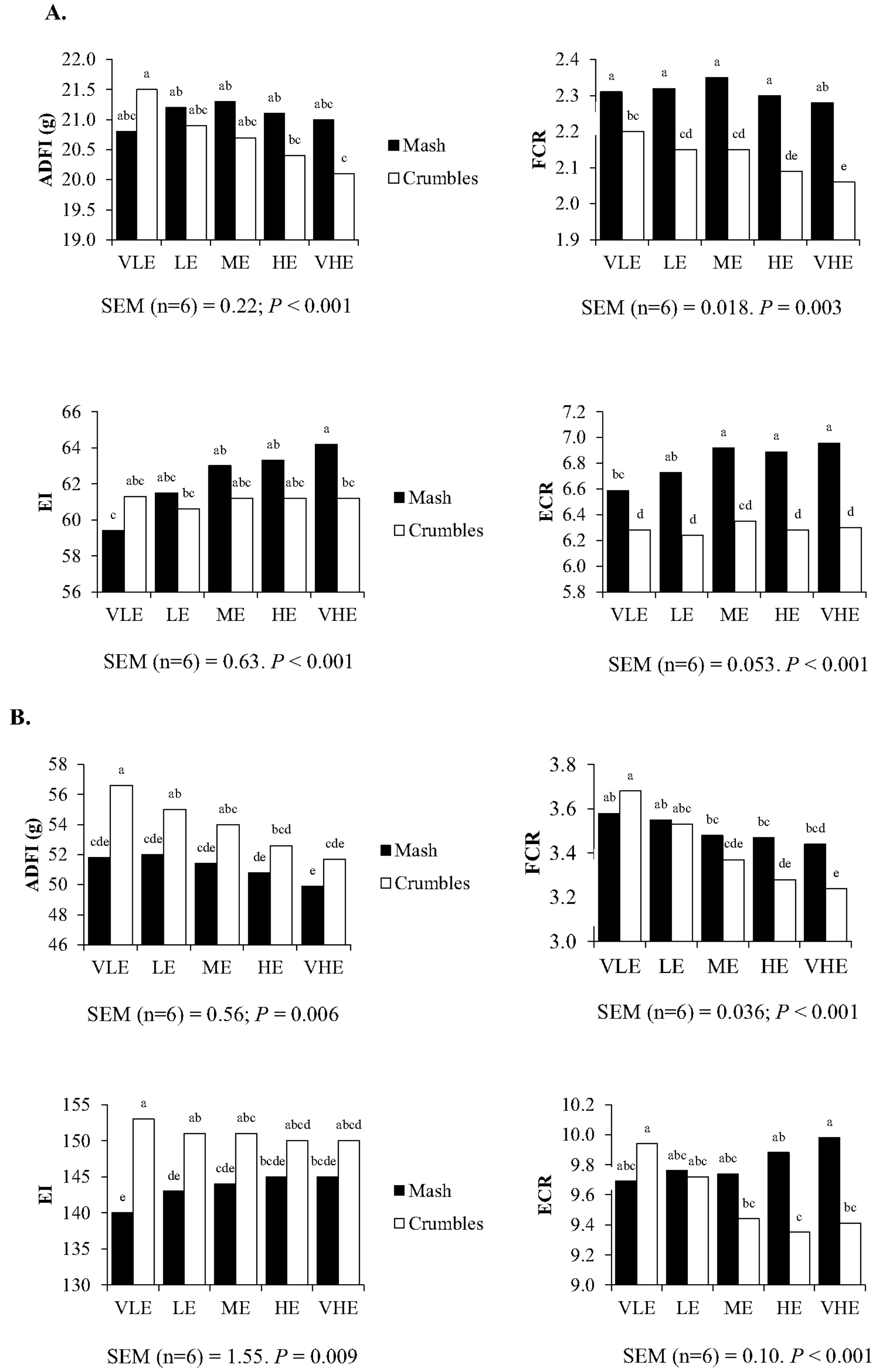

Figure 1. Interaction between feed form and energy content[1] (kcal AME_n/kg) of the diet on ADFI, feed conversion ratio (FCR), energy intake (EI, kcal AME_n/d), and energy conversion ratio (ECR, kcal AME_n/g BWgain) from 0 to 5 wk of age (A) and from 5 to 10 wk of age (B). [1]The AME_n content varied in 50 kcal/kg between diets [very low energy (VLE), low energy (LE), medium energy (ME), high energy (HE), and very high energy (VHE)]. [a–e]Means without a common superscript differ significantly.

FCR than pullets fed mash, consistent with most research published in broilers (Serrano et al., 2012; Abdollahi et al., 2013; Jiménez-Moreno et al., 2015) and pullets (Frikha et al., 2009b; Guzmán et al., 2015). Poultry require more time and energy for compacting feed particles when the diets are presented as mash than when presented as crumbles (Jensen et al., 1962; Savory and Hetherington, 1997). Consequently, pullets fed mash might consume less feed than pullets fed crumbles. In addition, the heat and pressure applied

Table 8. Influence of feed form and energy content (kcal AME_n/kg) of the diet on the carcass yield[1] and relative weight of the liver (% BW) of the pullets.

	5 wk			10 wk			17 wk		
Treatment	BW (g)	Carcass yield	Liver	BW (g)	Carcass yield	Liver	BW (g)	Carcass yield	Liver
Feed form									
Mash	371	81.7[b]	3.69[a]	911	85.4[b]	2.70	1,496	88.5[b]	2.10
Crumbles	396	83.3[a]	3.50[b]	967	87.1[a]	2.67	1,606	89.4[a]	2.14
AME_n content[2]									
VLE	372	82.2	3.55	956	86.2	2.66	1,552	88.6	2.18
LE	388	82.6	3.69	938	86.2	2.73	1,549	89.2	2.07
ME	385	82.9	3.58	938	86.2	2.73	1,552	88.9	2.10
HE	384	82.5	3.60	916	86.2	2.70	1,596	88.9	2.05
VHE	386	82.4	3.55	945	86.5	2.65	1,505	89.3	2.20
SD[3]		0.83	0.250		1.01	0.204		1.04	0.255
					P-value[6]				
Feed form		<.001	0.006		<.001	0.602		0.001	0.566
AME_n content									
L[4]		0.525	0.647		0.483	0.873		0.195	0.955
Q[5]		0.060	0.342		0.513	0.247		0.888	0.117

[1]Calculated as a percentage of the empty BW (including the head, neck, and feet and without GIT and digesta contents) and BW.

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[3]Thirty and 12 replicates of 2 birds each, for feed form and AME_n content of the diet, respectively.

[4]L = Linear effect of energy content of the diet.

[5]Q = Quadratic effect of energy content of the diet.

[6]The interactions between feed form and AME_n content of the diet were not significant ($P > 0.05$).

[a,b]Within a column, means without a common superscript differ significantly.

Table 9. Influence of feed form and energy content (kcal AME_n/kg) of the diet on the relative weight (RW, % BW[1]) and digesta content of the proventriculus (expressed as percent full organ weight) of the pullets.

	5 wk		10 wk		17 wk	
Treatment	RW	Content	RW	Content	RW	Content
Feed form						
Mash	0.79	6.13[b]	0.58	6.2[b]	0.54[b]	6.4[b]
Crumbles	0.82	13.38[a]	0.62	12.3[a]	0.65[a]	11.4[a]
AME_n content[2]						
VLE	0.77	7.77	0.58	10.1	0.57	10.2
LE	0.80	9.68	0.63	10.6	0.59	7.8
ME	0.80	9.18	0.61	8.3	0.58	8.9
HE	0.82	11.24	0.60	8.3	0.63	8.9
VHE	0.82	10.88	0.60	9.0	0.60	8.7
SD[3]	0.090	4.77	0.075	4.58	0.083	4.28
			P-value[6]			
Feed form	0.242	<.001	0.062	<.001	<.001	<.001
AME_n content						
L[4]	0.133	0.079	0.984	0.348	0.262	0.592
Q[5]	0.719	0.701	0.378	0.767	0.611	0.481

[1]The BW of the pullets are shown in Table 9.

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[3]Thirty and 12 replicates of 2 birds each, for feed form and AME_n content of the diet, respectively.

[4]L = Linear effect of energy content of the diet.

[5]Q = Quadratic effect of energy content of the diet.

[6]The interactions between feed form and AME_n content of the diet were not significant ($P > 0.05$).

[a,b]Within a column, means without a common superscript differ significantly.

during the pelleting process might modify the structure of the starch and the protein fraction of the feed (Gracia et al., 2009; Zimonja and Svihus, 2009), increasing energy (Jiménez-Moreno et al., 2009b) and CP (Lacassagne et al., 1988) digestibility. Moreover, fine grinding and pelleting disrupt the outer coat of the seed and fracture the endosperm of the grain, releasing the intracellular oil contained in the spherosomes of the corn and facilitating the access of digestive enzymes to nutrients (Calet, 1965; Mateos et al., 2002). On the other hand, crumbling reduces the particle size of the feed (Guillou and Landeau, 2000; Amerah et al., 2008) and a reduction in size increases rate of feed passage through the upper part of the GIT and increase voluntary FI (Hamm and Stephenson, 1959; Mateos et al., 2012).

From hatching to 5 wk of age, pullets fed crumbles ate less feed than those fed mash whereas an opposite effect was observed from 5 to 17 wk of age. However, ADG was greater and FCR was better in pullets fed crumble for all periods. Guzmán et al. (2015) reported also higher ADG but lower ADFI in pullets from 0 to 5 wk of age when fed crumbles than when fed mash. Probably, during the first period of life feed wastage was higher with mash than with crumbles but the differences disappeared with age. In this respect, Serrano et al. (2013) reported that the differences in feed wastage between crumbles and mash tended to decrease with age, consistent with the results of the current study.

Table 10. Influence of feed form and energy content (kcal AME_n/kg) of the diet on the relative weight (RW; % BW[1]), digesta content (expressed as percent to full organ weight), and pH of the gizzard of the pullets.

	5 wk			10 wk			17 wk		
Treatment	RW	Content	pH	RW	Content	pH	RW	Content	pH
Feed form									
Mash	5.08[a]	31.5[a]	2.97[b]	4.60[a]	28.4	2.72[b]	3.65[a]	27.1[a]	3.26[b]
Crumbles	3.79[b]	29.1[b]	3.17[a]	3.26[b]	24.5	3.41[a]	2.38[b]	12.1[b]	4.03[a]
AME_n content[2]									
VLE	4.55	30.3	3.19	3.94	26.9	2.94	3.14	22.1	3.57
LE	4.58	32.0	3.05	4.06	28.2	2.98	2.91	18.8	3.75
ME	4.32	31.0	2.95	3.96	26.0	3.19	3.05	19.9	3.61
HE	4.38	30.2	3.09	3.96	28.0	3.05	3.03	18.9	3.67
VHE	4.35	28.1	3.07	3.73	23.2	3.17	2.95	18.5	3.63
SD[3]	0.500	4.66	0.356	0.519	7.854	0.402	0.332	5.20	0.357
					P-value[6]				
Feed form	<.001	0.048	0.026	<.001	0.060	<.001	<.001	<.001	<.001
AME_n content									
L[4]	0.192	0.145	0.619	0.276	0.298	0.152	0.404	0.138	0.917
Q[5]	0.718	0.162	0.231	0.284	0.355	0.708	0.733	0.522	0.548

[1]The BW of the pullets are shown in Table 9.

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[3]Thirty and 12 replicates of 2 birds each, for feed form and AME_n content of the diet, respectively.

[4]L = Linear effect of energy content of the diet.

[5]Q = Quadratic effect of energy content of the diet.

[6]The interactions between feed form and AME_n content of the diet were not significant ($P > 0.05$).

[a,b]Within a column, means without a common superscript differ significantly.

BW uniformity was better in pullets fed crumbles than in pullets fed mash at all ages, with differences being significant at 10 and 17 wk of age. These results agree with data of Guzmán et al. (2015) who reported a trend for better BW uniformity with crumbles at 5 wk of age. Similarly, Brickett et al. (2007) reported an improvement in BW uniformity of 35-day-old broilers with pellet feeding.

Energy Concentration of the Diet Energy concentration of the diet affected pullet performance in different ways. From hatching to 17 wk of age, ADFI decreased with increases in energy content of the diet but EI was not affected. Birds have the ability to regulate voluntary FI to satisfy their energy requirements and therefore, ADFI decreases and FCR improves as the energy concentration of the diet increases. In the current study, the decrease in FI and the improvement in FCR with increases in dietary energy concentration were evident from 0 to 5 and 5 to 10 wk of age in pullets fed crumbles but not in pullets fed mash. In both feeding periods, EI increased as the energy content of the mash diets increased but no changes occurred in pullets fed crumbles. The differences observed between feed forms with increases in dietary energy content, might have been due to higher wastage with mash feeding (Guzmán et al., 2015). An increase in feed wastage with the mash diets might have counteracted the beneficial effect of an increase in dietary energy on EI. Probably, young pullets have less ability to increase voluntary FI when low-energy, bulkier diets are fed in mash form, as has been shown in broilers by Scott (2002) and Brickett et al. (2007). After 10 wk of age, however, the GIT of the pullets is well-developed with sufficient capacity to increase voluntary FI when fed low-energy diets.

BW uniformity was not affected by energy concentration of the diet at any age, in agreement with data in broilers (Brickett et al., 2007) and pullets (Frikha et al., 2009a; Guzmán et al., 2015). The data indicate that when the main objective is to increase flock uniformity, pullets respond better to changes in feed form than to increases in energy content of the diet.

GIT Traits and Body Measurements

Feed Form Diet structure has a strong influence on the anatomy and physiology of the GIT of broilers (Mateos et al., 2012) and pullets (Frikha et al., 2009b). At 17 wk of age, pullets fed crumbles had lighter gizzards and GIT and heavier proventriculi than pullets fed mash, consistent with data of Choi et al. (1986) and Nir et al. (1994a, b) in broilers. Jiménez-Moreno et al. (2010) and Abdollahi et al. (2011) reported that a decrease in particle size, as occurred when the diets were pelleted, led to faster rate of passage, with the digesta remaining for less time in the gizzard, which in turn reduced the development of the muscular layers of this organ. The RW of the full proventriculus was higher in pullets fed crumbles than in pullets fed mash, consistent with the increase in digesta content observed. As a result, carcass yield was higher in pullets fed crumbles that in pullets fed mash.

Table 11. Influence of feed form and energy content (kcal AME_n/kg) of the diet on the relative length (cm/kg BW[1]) of the small intestine and ceca of the pullets.

Treatment	5 wk Small intestine	5 wk Ceca	10 wk Small intestine	10 wk Ceca	17 wk Small intestine	17 wk Ceca
Feed form						
Mash	276[a]	56.2[a]	139	31.8[a]	87.0	20.4[a]
Crumbles	262[b]	52.8[b]	135	29.8[b]	84.3	19.4[b]
AME_n content[2]						
VLE	269	54.2	133	30.0	86.4	20.1
LE	258	54.2	148	31.5	85.4	19.8
ME	269	54.2	133	31.4	86.1	19.9
HE	273	53.9	135	30.5	85.0	19.8
VHE	275	56.0	136	30.5	85.3	19.9
SD[3]	17.8	4.50	15.3	3.41	5.48	1.54
			P-value[6]			
Feed form	0.005	0.005	0.491	0.032	0.065	0.021
AME_n content						
L[4]	0.110	0.438	0.626	0.977	0.631	0.733
Q[5]	0.339	0.419	0.617	0.324	0.878	0.684

[1]The BW of the pullets are shown in Table 9.

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[3]Thirty and 12 replicates of 2 birds each, for feed form and AME_n content of the diet, respectively.

[4]L = Linear effect of energy content of the diet.

[5]Q = Quadratic effect of energy content of the diet.

[6]The interactions between feed form and AME_n content of the diet were not significant ($P > 0.05$).

[a,b]Within a column, means without a common superscript differ significantly.

The RW of the empty proventriculus was higher in pullets fed crumbles than in pullets fed mash (data not shown), suggesting that crumbles cause a hypertrophy of this organ (Mateos et al., 2012). In this respect, Svihus (2011) indicated that an excess of digesta might result in higher incidence of ruptures of the walls of the proventriculus at the slaughterhouse and an increase in contamination of the carcasses. Crumbles reduced gizzard digesta content at all ages and gizzard pH, results that agree with data of Engberg et al. (2002) and Serrano et al. (2013) in broilers and Frikha et al. (2009b) in pullets. In contrast, Dahlke et al. (2003) did not observe any effect of pelleting on gizzard pH in 42-day-old broilers.

Feeding crumbles decreased the RL of the small intestine and ceca at all ages, consistent with data of Frikha et al. (2009b) in 6-week-old pullets. In broilers, Nir et al. (1994a) reported that pelleting reduced the RL of the jejunum and ileum, in agreement with the results of the current research. Amerah et al. (2007) suggested that a decrease in the RL of the GIT was positively correlated with the growth of the chicks, consistent with the results reported herein.

Body length and tarsus length have been used as indirect measurements to predict chick growth (Senar and Pascual, 1997; Mendes et al., 2008). In the current study, pullets fed mash were longer and had longer and wider tarsus than pullets fed crumbles. The authors have not found any research on the effects of feed form on these variables in pullets to compare with the results reported herein. Zuidhof (2005) indicated that because of differences in the allometric growth of tissues and body organs, carcass yield increases as the BW of the bird increases. Interestingly, and in contrast with the relative values reported, absolute values for body length and tarsus length were higher for pullets fed crumbles than for pullets fed mash (data not shown). Consequently, data on weight and length of the different organs of the bird, as a consequence of feeding crumbles or mash, must be taken with caution.

Energy Concentration of the Diet The RW of the liver was not affected by the energy content of the diet at any age. In contrast, Scott (2002) reported lighter livers in 34-day-old broilers as the AME_n content of the diet increased. The reason for the discrepancy is not known but differences in diet composition (level of fat vs. level of starch and fiber) and on the capacity for FI between pullets and broilers, might explain the lack of agreement among researches.

Energy concentration of the diet did not affect the RW of the full proventriculus or gizzard at any age, in agreement with data of Keshavarz (1998). In contrast, Frikha et al. (2009a) observed that an increase in the AME_n concentration of the diet from 2,880 to 3,025 kcal/kg reduced gizzard weight of the pullets at 45 d of age. High-energy diets contain less fiber than

Table 12. Influence of feed form and energy content (kcal AME_n/kg) of the diet on relative body length (cm/kg BW[1]) and tarsus length (L) and diameter (D) of the pullets.

	5 wk			10 wk			17 wk		
Treatment	Body	Tarsus (L)	Tarsus (D)	Body	Tarsus (L)	Tarsus (D)	Body	Tarsus (L)	Tarsus (D)
Feed form									
Mash	109[a]	17.5[a]	1.75	63.8[a]	7.85[a]	0.91[a]	44.8[a]	5.20[a]	0.67[a]
Crumbles	103[b]	16.8[b]	1.75	61.3[b]	7.53[b]	0.87[b]	41.6[b]	4.75[b]	0.63[b]
AME_n content[2]									
VLE	108	17.4	1.77	62.1	7.59	0.88	43.1	4.96	0.64
LE	105	17.1	1.77	62.6	7.70	0.90	43.2	5.10	0.66
ME	105	17.0	1.75	62.1	7.73	0.88	43.0	4.87	0.63
HE	106	17.2	1.74	63.8	7.83	0.91	41.7	4.87	0.64
VHE	104	17.1	1.72	62.0	7.60	0.88	45.0	5.08	0.67
SD[3]	5.64	0.85	0.105	3.14	0.372	0.044	3.07	0.392	0.081
					P-value[6]				
Feed form	<.001	0.005	0.225	0.003	0.001	0.009	<.001	<.001	0.035
AME_n content									
L[4]	0.164	0.586	0.666	0.741	0.679	0.837	0.430	0.853	0.789
Q[5]	0.637	0.354	0.827	0.482	0.107	0.446	0.115	0.349	0.509

[1]The BW of the pullets are shown in Table 9.

[2]The AME_n content varied in 50 kcal/kg between diets (VLE, very low energy; LE, low energy; ME, medium energy; HE, high energy; and VHE, very high energy).

[3]Thirty and 12 replicates of 2 birds each, for feed form and AME_n content of the diet, respectively.

[4]L = Linear effect of energy content of the diet.

[5]Q = Quadratic effect of energy content of the diet.

[6]The interactions between feed form and AME_n content of the diet were not significant ($P > 0.05$).

[a,b]Within a column, means without a common superscript differ significantly.

low-energy diets and a reduction in fiber content might reduce digestive organ size (Hetland and Svihus, 2001). In the current study, however, the crude fiber content of the lowest- and highest-energy diets did not vary much (i.e., from 4.1 to 3.2% crude fiber from 0 to 5 wk of age). Probably, the differences in insoluble fiber content among diets were too small to produce any marked difference in digestive organ size of the pullets.

In summary, feeding crumbles to pullets increased ADFI and ADG and improved FCR and BW uniformity from 0 to 17 wk of age but reduced the development and relative weight of the different organs of the GIT, including the gizzard. An increase in the energy content of the diet decreased ADFI and improved FCR but did not affect BW uniformity or GIT development at any age. Crumbles might be preferred to mash feeds when the main objective is to improve growth and BW uniformity of the pullets. Crumble feeding, however, might reduce FI early in the production cycle, because of a poor development of the GIT, reducing egg weight during the laying phase. On the other hand, the recommended energy content of the pullet diets will depend on feed form and the relative cost of available ingredients.

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